Lightweight ZERODUR®: Validation of mirror performance and mirror modeling predictions

SCHOTT
glass made of ideas

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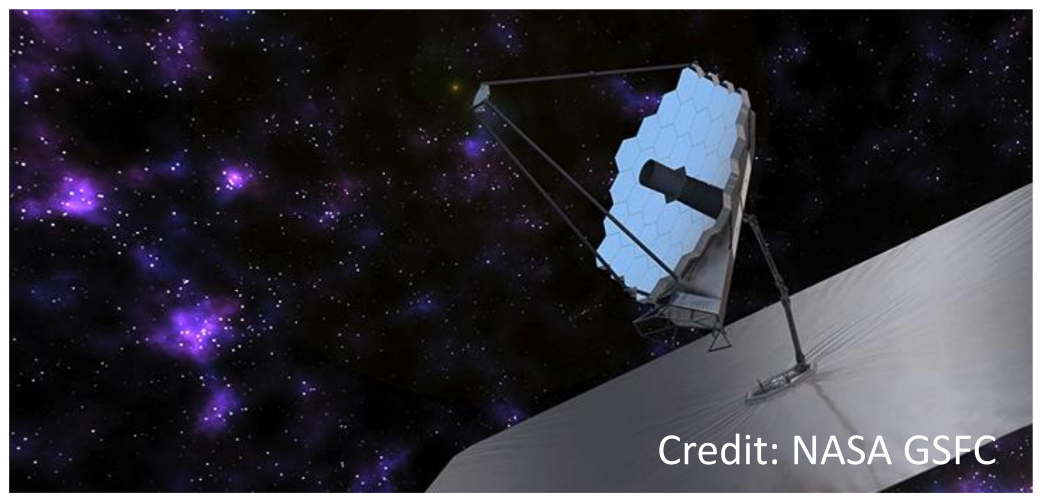
ABSTRACT

1. Upcoming spaceborne missions, both moderate and large in scale, require extreme dimensional stability while relying both upon established lightweight mirror materials, and also upon accurate modeling methods to predict performance under varying boundary conditions.
2. We describe tests, recently performed at NASA's XRCF chambers and laboratories in Huntsville Alabama, during which a 1.2m diameter, f/1.29 88% lightweighted SCHOTT lightweighted ZERODUR® mirror was tested for thermal stability under static loads in steps down to 230K.
3. Test results are compared to model predictions, based upon recently published data on ZERODUR®. In addition to monitoring the mirror surface for thermal perturbations in XRCF Thermal Vacuum tests, static load gravity deformations have been measured and compared to model predictions. Also the Modal Response (dynamic disturbance) was measured and compared to model.
4. We will discuss the fabrication approach and optomechanical design of the ZERODUR® mirror substrate by SCHOTT, its optical preparation for test by Arizona Optical Systems (AOS), and
5. Summarize the outcome of NASA's XRCF tests and model validations



Credit: NASA GSFC

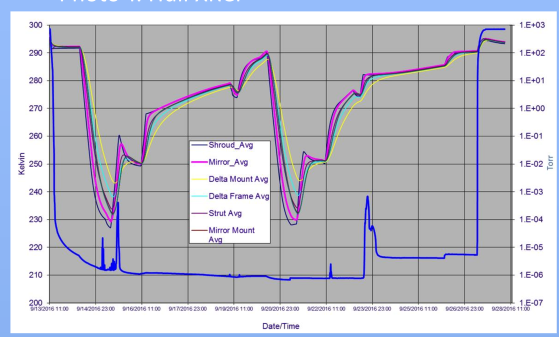
UPCOMING SPACE MISSIONS

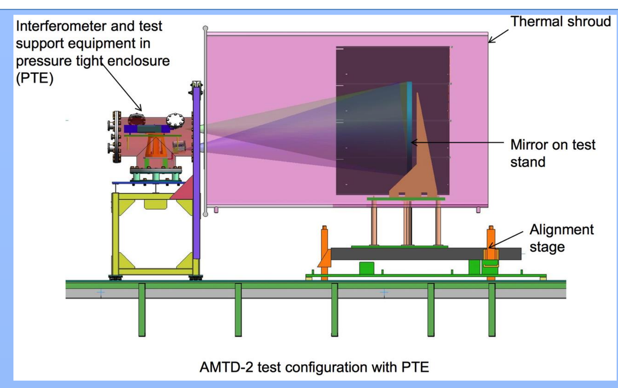
Both monolithic and segmented architectures are being considered for large future space missions. While segmented mirror approaches will reference The Webb Telescope architecture, diffraction limited at λ 2µm, the requirements will be much more refined for wavefront error, especially error stability over time. For exoearth imaging with large telescopes, stability at the level of 10 picometers over 10 minutes is anticipated. Even for smaller telescopes, coronagraphy and ultraviolet scoence will require stability of WFE one to two orders of magnitude better than The Webb Telescope. We discuss evaluation of ZERODUR® thermal stability and the ability to model expected WFE performance of a representive lighewieght ZERODUR® mirror made by SCHOTT under rigorous thermal vacuum tests at XRCF.

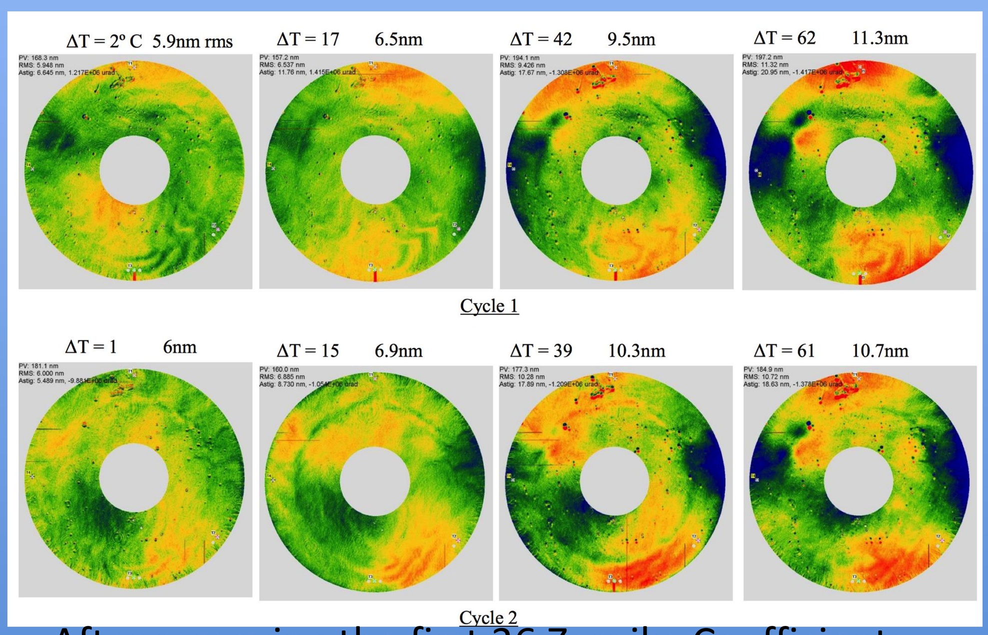
XRCF at MSFC:
Credit: NASA MSFC

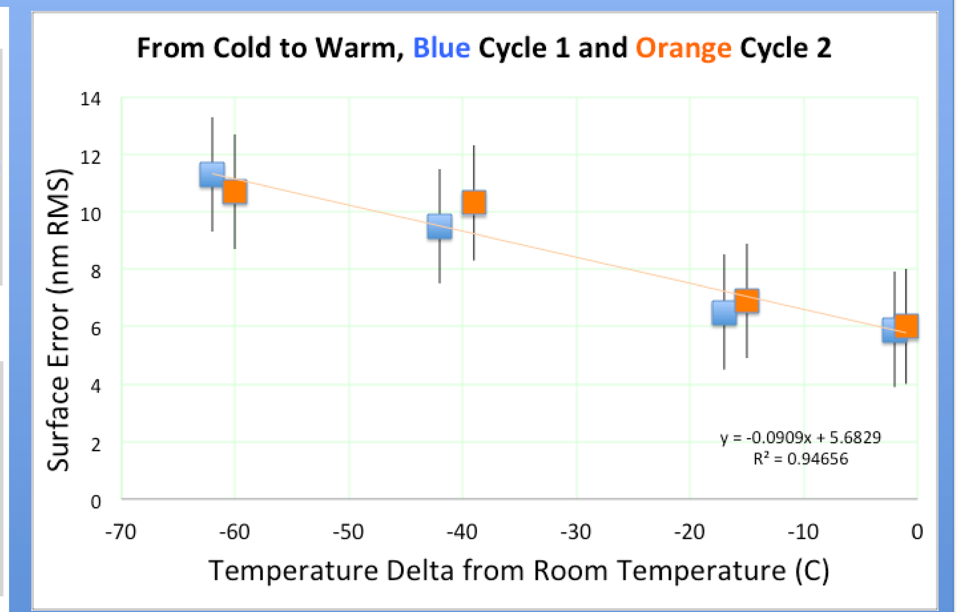
XRCF Tests

Photo T. Hull XRCF

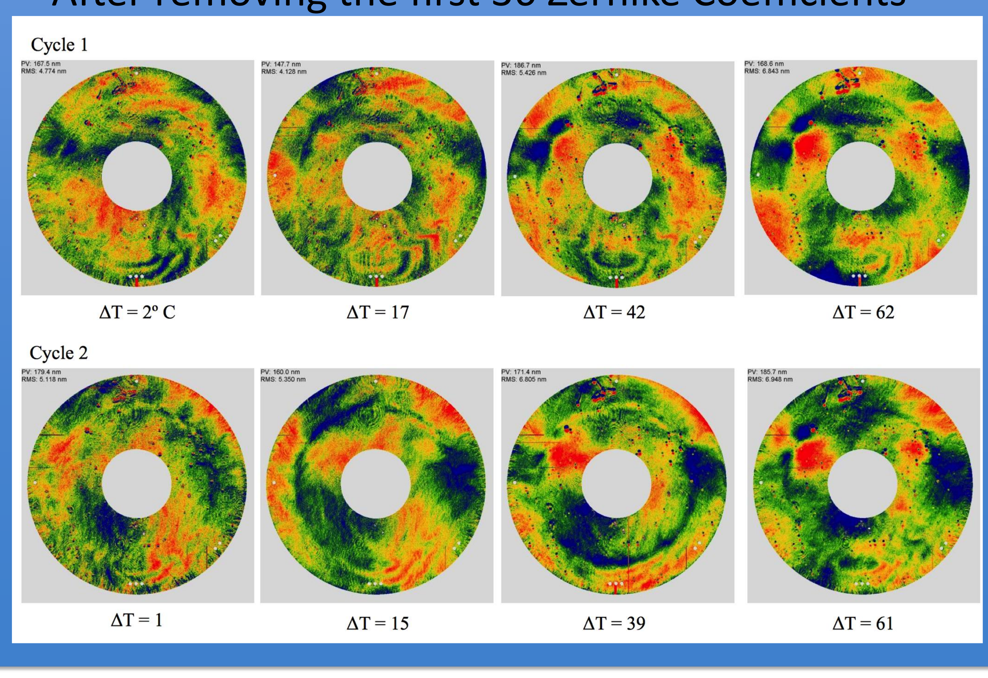






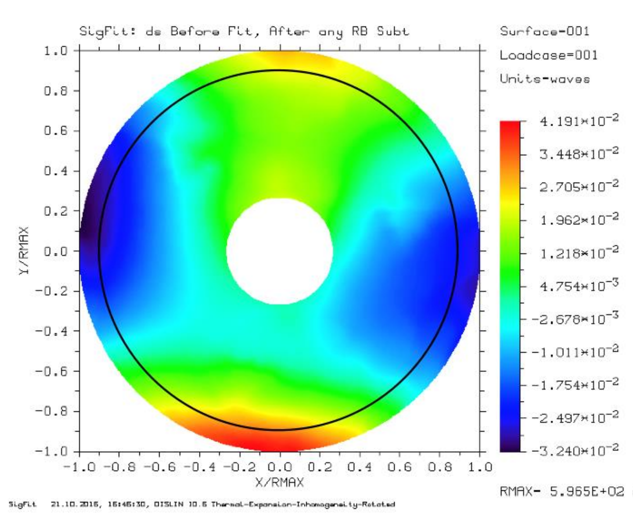


After removing the first 36 Zernike Coefficients



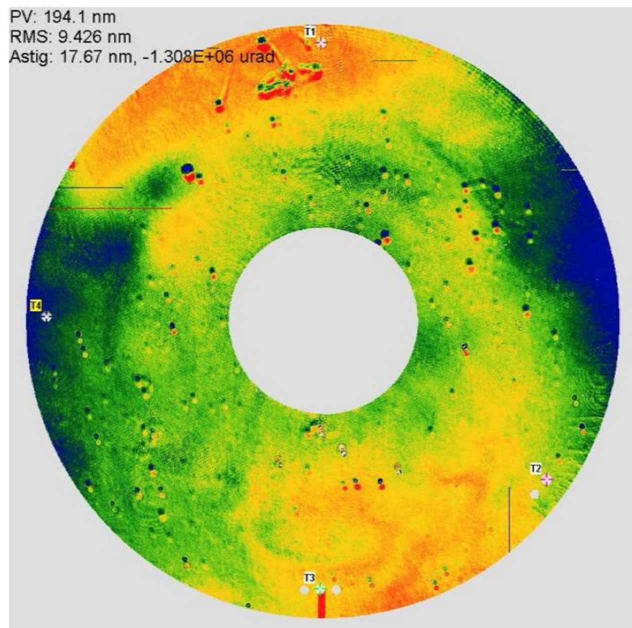
- While there may appear to be a weak linear trend, it is small compared with systematic errors. The main error is astigmatism.
- After subtraction of the first 36 Zernikes, most remaining artifacts seem to associate with the mounting points, and difficult to separate between mounting and mirror itself.
- The mount is very repeatable at ambient, but it was designed under restrictive cost constraints, and thus is neither fully athermal, nor optimized against thermal gradients.

Modeling the Schott ELZM Thermal Soak Test



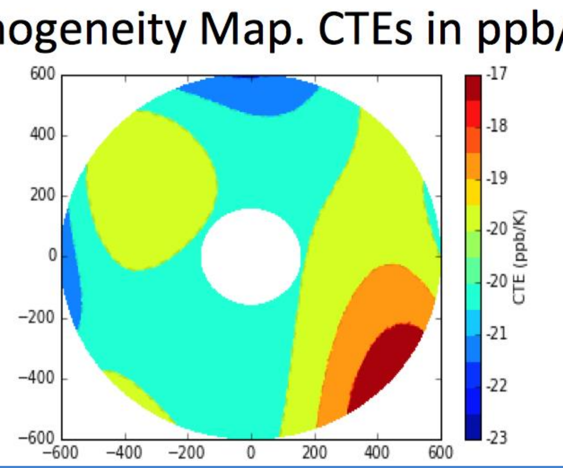
New Homogeneity* (9.55 nm RMS)

*CTE Inhomogeneities randomly generated until one matched. P-V homogeneity changed to 5 ppb/K.



Measured SFE (9.4 nm RMS)

Homogeneity Map. CTEs in ppb/K

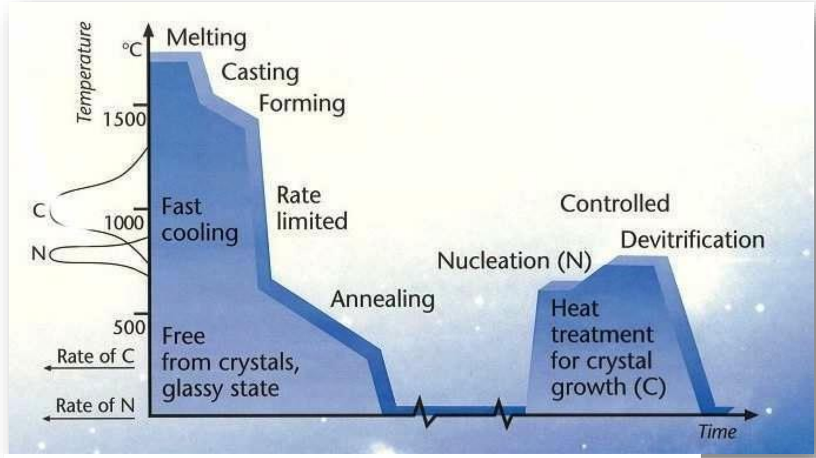


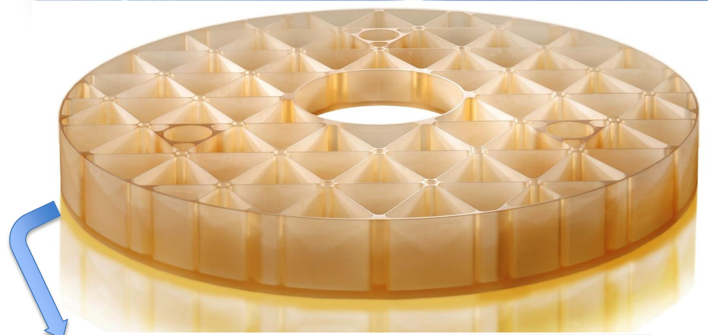
Conclusion

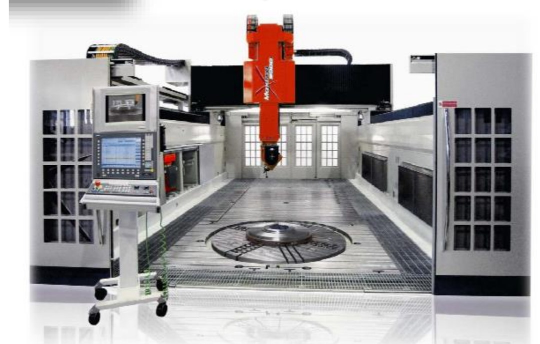
- A 5 ppb/K peak-to-valley inhomogeneity produced 9.55nm RMS of SFE and a root-sum-squared SFE estimate of 9.6nm RMS.
- Zerodur boules have been measured to have a 5 ppb/K peak-to-valley CTE inhomogeneity, therefore, 5ppb/K peak-to-valley inhomogeneity is reasonable.
- Further investigation will match test results to an even greater extend.

Ralf Jedamzik, et al.
" Effects of thermal inhomogeneity on 4m class mirror substrates ", Proc. SPIE 9912, Advances in Optical and Mechanical Technologies for Telescopes and Instrumentation II, 99120Z (July 22, 2016); doi:10.1117/12.2234287; http://dx.doi.org/10.1117/12.2234287

OPTOMECHANICAL DESIGN & FABRICATION APPROACH

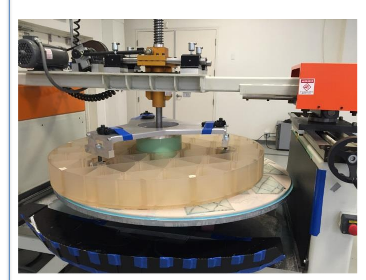




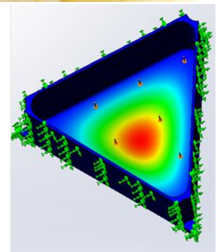


5-axis CNC machinery and precision etching to remove machining damage is used to lightweight ZERODUR®. Above is a 4-m 5-axis machine to be in place at Mainz in Q1 2017.

Ground with a full sized tool for efficiency on Draper



AOS designed and built a custom mechanism to stroke the ELZM across the grinding tool without imparting a moment into the substrate

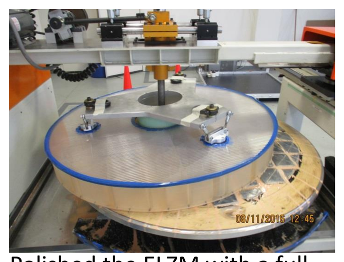


FE model of cell quilting under grinding load

ELZM laser tracker measurement

- FEA was used to analyze the stroker mechanism and the cell pressure to minimize quilting effects to < 10nm RMS
- The ELZM surface was measured using mechanical spherometers and a laser tracker system during grinding operations

ELZM during polishing process on Draper



Polished the ELZM with a full sized tool for efficiency and measured using interferometer

ELZM during testing, mounted to AOS support

- The mirror was polished to "interferometric capture", not to full surface requirements of future missions. This was to conserve cost.
- Also under Design-to-Cost constraints, AOS designed and built finger flexures and a bipod flexure support structure to mount the ELZM during testing at AOS and at subsequently at XRCF
- At XRCF under ambient temperature, the support performed within 1nm RMS of predicted value by AOS over full temperature range

Conclusions:

The SCHOTT 1.2m ELZM mirror was measured for optical figure variation in thermal-vacuum in the large XRCF chamber at MSFC. The intent is to see if bulk ZERODUR® properties are maintained on a mirror blank with machined lightweighting leaving sections as thin as 2mm.

Temperature dependent of surface errors is consistent with the latest values of extensive CTE homogeneity tests at SCHOTT [Jedamzik, et al. 2016]

Measurements are consistent with a set of MSFC models assuming a ZERODUR® inhomogeneity magnitude of 5 ppb/K.

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Visit the SCHOTT AAS display and see the tested 1.2m ELZM mirror